CHLORINATION OF POTABLE WATER

SUPPLIES

Revised March 1980

Ministry
of the
Environment

Ontario

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POLLUTION CONTROL BRANCH

Revised March, 1980

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INDEX

Ontario Ministry of the Environment

Bulletin

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1.0 Introduction

1.1 Purpose of Bulletin

Disinfection, to kill pathogenic organisms, is the most important step in any water treatment process. In Ontario it is usually accomplished by adding chlorine. This chemical has many other uses in water treatment such as coagulation aid, taste and odour control and maintenance of water quality in the distribution system, but its primary purpose is disinfection. This bulletin outlines the requirements to achieve adequate disinfection and the procedures to follow when it is not achieved. The bulletin also outlines a design standard. New installations should meet the criteria as set out in the bulletin and existing facilities should be brought up to these standards.

1.2 When is Disinfection Required?

Continuous and adequate disinfection is required when the supply is obtained from a surface source; when ground water sources are or may become contaminated, as in fractured limestone areas; when the supply is exposed to contamination during treatment or when emergency conditions such as flooding or epidemic, indicate the need. Disinfection equipment should also be available at those plants where continuous disinfection is not required, to allow temporary disinfection if unsatisfactory or poor bacteriological quality of water is reported. The design of all plants should incorporate suitable connections for disinfecting equipment to be added for this purpose.

1.3 Types of Chlorination

Chlorine when added to water immediately dissociates into hypochlorous acid and hydrochloric acid. The former compound can

further dissociate to hypochlorite ion and hydrogen. Hypochlorous acid predominates when the pH is below 7.5. It is the compound that is the prime disinfecting agent in a free chlorine residual. However it is very reactive and will quickly combine with certain compounds (eg. ammonia) and slowly with many other compounds, that may be present in water, to produce a combined chlorine residual (monochloramine, dichloramine etc.). When sufficient chlorine is present so that the reactions that form the combined chlorine are completed, the breakpoint has been reached. The addition of more chlorine will then yield a free chlorine residual.

Of the many regimes of chlorination, simple or marginal chlorination is probably the most common. This is also probably the least effective, especially if it is the only treatment applied to surface water. Chlorine is applied to give an initial total chlorine residual of 0.2 - 0.5 mg/L, predominantly as a combined residual that frequently disappears in the distribution system.

Free residual chlorination produces a much superior disinfecting agent. Sufficient chlorine should be added so that the free residual comprises about 60 to 80 percent of the total residual and it should be maintained through all of the water treatment plant and distribution system. Very high free residuals (super-chlorination) would necessitate at least partial dechlorination, before entering the distribution system, with sulphur dioxide, sodium thiosulphate or activated carbon. The addition of ammonia will produce the more stable but less active disinfectant, chloramine.

If only a chloramine residual is desired, it can be achieved by adding ammonia before the chlorine. However a much higher dose and/or much longer contact time is required to achieve the same degree of disinfection as a free chlorine residual.

Pre-chlorination together with post-chlorination, as required is a frequent mode of operation at Ontario water treatment plants. If organic compounds in the raw water tend to cause formation of chlorinated organics (chloroform, etc) it may be advisable and possible to chlorinate just prior to or after filtration when many organic

precursors may have been removed. However, the bacteriological integrity of the water must receive first priority when considering any modification to chlorination practices aimed at reducing the formation of chloro-organics.

2.0 Equipment

Chlorination equipment must be readily available at all water treatment plants. This includes all ground water supplies where chlorination is not continuous.

2.1 Capacity

Chlorination equipment shall have a maximum feed capacity at least 50% greater than the highest expected dosage required to provide a free chlorine residual of 1.0 mg/L in the finished water.

2.2 Duplicate Equipment

Chlorine feed equipment (both gas and hypochlorite chlorinators) at waterworks where disinfection is required, shall be installed in duplicate, to provide uninterrupted chlorination in the event of a breakdown. In addition, spare parts consisting of at least the commonly expendable parts such as glassware, rubber fittings, hose clamps and gaskets, should be provided for effecting emergency repairs.

For a multi-well supply system requiring chlorination for disinfection the standby requirements may be met by one portable unit.

2.3 Chlorinators and Controls

Dependable feed equipment, either of the gas feed or positive displacement solution feed type, shall be used for adding chlorine. Automatic proportioning of the chlorine dosage to the rate of flow of water should be provided at all plants, especially where the rate of flow varies without manual adjustment, or operation of valves and/or switches. Where the chlorine demand is not constant, it may also be necessary to either adjust the chlorine dose through

a chlorine residual analyzer, or feed a constant chlorine dose and use the chlorine residual analyzer to regulate the feed of a dechlorinating agent.

2.4 Gas Chlorination

2.4.1 Building Design

Gas chlorine equipment - (chlorinators, weigh scales, chlorine cylinders) must be located in an isolated room or rooms. In larger installations the storage and weighing facilities should be in a room separate from the chlorinators. The construction of the facility should be of fire-resistant and corrosion proof material, have concrete floors and be gas tight. All interior surfaces should be coated with a substance impermeable to chlorine gas.

A set of corrosion resistant scales should be available for weighing the chlorine cylinders. Scales for 69 kgm (150 lb.) cylinders should be of the low profile type. Non-low profile scales shall be recessed in the floor. Safety chains shall be used to retain each cylinder, in storage and on weigh scales, in a safe upright position.

Chlorine should not be stored below ground level and the cylinders must be protected from excessive heat, dampness and mechanical damage. One ton cylinders shall be stored on their sides on level racks.

Where rail cars are used, a dead end siding restricted to chlorine tank cars shall be provided. The tracks must be level and protected by a locked derail or a locked closed switch.

Areas containing chlorine or chlorination equipment shall be clearly marked "Danger! Chlorine Storage" or "Danger! Chlorine Feed Equipment" as applicable. The exit doors with "panic" hardware shall be hinged to open outwardly. There shall be two or more exits if the distance to travel to the nearest exit exceeds 15 feet. All exits from the chlorine room and storage area should be to an outside wall. Access between these rooms is permitted if they have a common wall.

The temperature in the chlorine storage and scale room shall not be higher, and preferably slightly lower than that in the chlorinator room. The gas lines between the scales, chlorinators and injectors shall not be located directly on an outside wall or in a location where low temperatures may be encountered.

2.4.2 Safety Equipment

Each plant shall have readily available, a self-contained or air-supplied respirator of the pressure demand type. One respirator shall be located in a conspicuous location outside the area of probable contamination.

Protective clothing including gloves, goggles and safety shoes shall be available for persons handling chlorine.

Eye wash fountains shall be located as near as possible but outside the area of probable contamination.

All chlorine rooms must have a chlorine leak detector alarm system.

Container emergency kits to repair leaking valves, fusible plugs or the tanks themselves are available from chlorine suppliers. There are different kits for each size of tank and the proper size should be available at each water plant.

2.5 Hypochlorite Chlorination

It is important that hypochlorite compounds which contain an algicide not be used as a disinfecting agent in potable water systems.

2.5.1 Safety Procedures

Sodium hypochlorite (a liquid) and calcium hypochlorite (a powder) are frequently used to provide chlorination at small municipal water plants and to disinfect mains and reservoirs. Certain safety precautions must be observed in the storage and handling of these compounds.

Calcium Hypochlorite

Certain precautions must be taken when adding granular calcium hypochlorite.

1) Store containers in a clean, cool, dry area away from any combustible material. Spontaneous combustion can result from improper storage. Keep the containers away from moisture, heat and fire. There should be no smoking in this area.

2) Metal drums should be kept upright and should not be dropped, rolled or skidded. Calcium hypochlorite, if dropped, can explode and burn.

3) Empty containers should be thoroughly rinsed with water.

4) When handling calcium hypochlorite it must never have contact with the eyes and it can cause serious burns in the lungs or on damp skin. Face shields with dust masks together with long gloves and other protective clothing must be worn.

5) When measuring calcium hypochlorite a plastic, glass or enameled device that is clean and dry must be used. It should only be mixed with water.

Sodium Hypochlorite

Sodium hypochlorite is much safer than calcium hypochlorite but does require much more storage space and is more costly to transport long distances.

1) There is no fire hazard from the storage of sodium hypochlorite but corrosion from spillage can be a problem if the facilities are not corrosion resistant and cannot be well flushed with water.

2) When handling the chemical, proper clothing (gloves, eye goggles, etc.) shall be worn.

2.5.2 Chlorination Procedures

Where a powdered product is used, hypochlorite solution shall be prepared in a separate tank to allow clarification by settling before it is directed to the solution storage tank serving the hypochlorinator. If the water used to dissolve the granular hypochlorite has a hardness in excess of 100 ppm, the water should be softened with hexametaphosphate (Calgon) or an ion exchange unit. Periodic purging of the metering system, with muriatic acid, may be necessary to remove calcium deposits. The acid must be flushed from the system before it is put back into use.

The stability of the hypochlorite solution is increased if the concentration is low; the pH is above 10; iron, copper and nickel content is low; and the solution is stored in the dark at low temperature.

2.6 Chlorine Residual Testing

It is important that all surface water supplies be equipped with a continuous chlorine residual analyzer and recorder as well as a continuous turbidity analyzer and recorder; this is especially so at larger plants and where water near the intake could become polluted. All surface water plants should at least be equipped with an alarm system that would indicate when the chlorination equipment malfunctions.

Ground water sources, where poor water quality and/or minimum supervision indicates a possible health hazard, should have an automatic chlorine residual analyzer and recorder equipped with a high and low residual alarm or at least an alarm system that would indicate when the chlorination equipment malfunctions.

All installations must be equipped with a permanent standard chlorine residual testing device. It is preferable to use a DPD comparator test kit, an amperometric titrator or equivalent. The amperometric titrator can be used to check the accuracy of a

continuous chlorine residual analyzer. The above methods can be used to measure a free chlorine residual in the finished water, the distribution system or in the stand pipe when an emergency or other circumstances require a free residual.

3.0 Routine Operation

3.1 Chlorine Residual

3.1.1 General

Chlorine can be present in water as either a free or a combined residual. The bactericidal effectiveness of both residual forms is markedly reduced by high pH or turbidity, while it is enhanced by a higher temperature or a longer contact time. A free chlorine residual, while a much more effective disinfectant, also readily reacts with ferrous iron, manganese, sulphides and organic material to produce compounds of no value for disinfection.

3.1.2 Requirements

For surface water treatment plants achieving low uniform turbidities (1 FTU or less) with a minimum of 2 hours of chlorine contact or for ground water supplies proven free of hazardous bacterial or viral contamination but still requiring chlorination, the minimum total chlorine residual shall be 0.2 mg/L. For all other chlorinated supplies the minimum total chlorine residual shall be 0.5 mg/L. These are minimum acceptable residuals not target or objective residuals. A minimum contact time of 15 minutes (preferably 30 minutes) before the first possible consumer shall be provided at all times. The chlorine residual should be differentiated into its free and combined portions. It is preferable that most of the residual be a free residual. Adequate disinfection may not occur at these minimum levels if the pH is above 7.5 or the turbidity above 1 FTU.

As circumstances demand, the minimum requirements for chlorine residual and/or contact time may be increased.

The chlorine residual test must be performed as frequently as needed to ensure that an adequate chlorine residual is maintained at all times. Such considerations as raw water quality and the resultant variation in chlorine demand, and changing flow rates must be taken into account.

The accuracy of an automatic chlorine residual analyzer shall be checked daily. This shall be accomplished using the amperometric titrator. The results of the check shall be inscribed on the recording chart along with the date and operator's initials opposite a mark indicating the time of the check.

A chlorine residual should be maintained in all parts of the distribution system. This will do little to protect the supply in the event of a main break or some other disaster but should control nuisance growths. The residual should be differentiated into its free and combined portions. The pH of the sample should also be recorded so that the major chlorine constituents in the water can be determined.

The amount and type of chlorine residual present when routine bacteriological samples are taken should be recorded, because this allows a more complete evaluation of the condition of the distribution system.

3.1.3 Determination

A representative sample of chlorinated water should be tested. From a tap, the water should be kept running for 5 minutes before taking the sample.

The time when the chlorine residual test should be made depends on where the sample was taken. If the sample has just been chlorinated it should be held for 15 minutes to simulate the minimum contact time, in a covered, demand-free container away from light and heat. However, a sample from the distribution system or finished water after a contact chamber should be tested immediately.

Determination of a chlorine residual should be done by one of the methods outlined in the most recent Standard Methods (14th Edition, 1976) which are preferable to the regular orthotolidine test which has been used extensively. At present the most widely accepted methods are the DPD (diethyl-p-phenylene diamine), both titrimetric and colorimetric, and the amperometric titration. For small water treatment plants or field testing a DPD comparator kit is accepted.

When using the DPD colorimetric (comparator) test a few important procedures must be observed.

1) The glass cell must be thoroughly rinsed after each test, since any trace of the potassium iodide (Tablet #3) will cause the chloramine colour to develop in the next test for free chlorine.

2) To facilitate dissolving the tablets, they can be crushed while still in their tinfoil packets.

3) Disintegrate tablet #1 in a few drops of the sample in the test cell. Fill the test cell to 10 ml and mix rapidly.

4) The free chlorine residual must be read within 30 seconds of adding the sample to the cell.

5) The total chlorine residual is determined by adding tablet #3 (crushed) to the same sample in the test cell, mixing, waiting 2 minutes for the full colour to develop and then reading the results in the comparator.

3.2 Records

Minimum records shall include:

1) Daily records of the chlorine used and scale readings.

2) Results from all chlorine residual tests, together with the flow rate and chlorine feed rate and the time of testing.

3) The daily water consumption and the chlorine dosage in milligrams per litre.

4) Details on chlorine cylinder changes, orders and chlorine on hand.

5) Monthly and yearly summaries of chlorine consumption and feed rates.

6) For surface supplies, daily air and water temperatures and weather conditions eg. rain, cloud, sunny, snow etc. together with wind direction and strength.

4.0 Emergency Operation

At all facilities supplying municipal drinking water, a procedure to follow in case of emergency (ie. plant malfunction) must be developed. A list of procedures for the operator to follow must be posted in a prominent location in the plant.

This list must include:

1) The order not to pump unchlorinated or inadequately chlorinated water to the distribution system.

2) The name, address and telephone number of:

   a) Senior supervisory personnel,

   b) Medical Officer of Health and an alternate in the regional health unit if the Medical Officer of Health cannot be reached,

   c) The local M.O.E. District Officer and an alternate,

   d) Chlorinator service company (to be called only if chlorinator needs servicing),

   e) Chlorine supplier (to be called when chlorine required or when tanks malfunction).

3) The exact procedure to follow in order to increase the total chlorine residual leaving the plant to a minimum of 1.5 mg/L.

Wherever chlorination is required, the Ministry of Environment and the Medical Officer of Health must be notified immediately if unchlorinated or inadequately chlorinated water (total residual below 0.2 or 0.5 mg/L or level required) is directed to the distribution system. If this has occurred the Ministry of Environment may require the chlorine feed rate to be increased to provide a 1.0 mg/L or higher residual leaving the plant. Extensive flushing may also be required to carry the residual through the distribution system. Depending on the circumstances additional steps may be required.

When the chlorine residual is increased all customers who may be adversely affected must be notified.

5.0 Adverse Bacteriological Results

When the results from bacteriological samples collected from the distribution system indicate unsatisfactory water quality on the basis of the Ontario Ministry of Environment Drinking Water Objectives, (presence of fecal coliform bacteria or the numbers of coliform bacteria five or more per 100 ml) the procedures to follow immediately are:

1) Notify the Ministry of the Environment (increased chlorine residuals may be advised),

2) Collect further samples to confirm the results and determine the extent of the contamination. Chlorine residuals should also be recorded.

If these samples still show unsatisfactory water quality, the Medical Officer of Health and the Ministry of the Environment must be notified and the chlorination increased to provide a total

chlorine residual of 1.0 mg/L or a free chlorine residual of 0.2 mg/L at the end of the distribution system. Systematic flushing or swabbing may be necessary in order to achieve and maintain a residual at the ends of the distribution system.

A thorough study of the treatment plant and/or distribution system should be undertaken to determine the cause of the adverse bacteriological results. If the conditions warrant it the Ministry of Environment should recommend to the Medical Officer of Health that a boil-water advisory be issued.

When the bacteriological samples indicate poor water quality (coliform bacteria present at levels below five per 100 ml in more than 10% of the monthly samples or other indicator bacteria - see MOE Drinking Water Objectives) the Ministry of the Environment may recommend some of the following procedures:

1) Initiate chlorination on an unchlorinated supply,

2) Increase the chlorine residual requirements in the finished water to 1.5 mg/L or more, and maintain the level until notified by MOE,

3) Establish a total or free chlorine residual to the end of the distribution system,

4) Disinfect the distribution system as for new mains (Sec. 6.2),

5) Undertake a thorough resampling of the distribution system which should continue until the water quality is again acceptable.

6.0 Disinfection of New and Repaired Mains

6.1 Preparation

Chlorine is predominantly a surface active disinfectant that will not penetrate debris rapidly to kill microorganisms. This

debris may also react with the chlorine to reduce its disinfecting power. For these reasons, prior to disinfection of new or repaired works, all the debris must be removed. This can be achieved by extensive flushing with potable water, preferably with foam swabs.

6.2 Disinfection of New Water Mains

There are three procedures outlined in the AWWA Standard C601-68.

a) Continuous Feed Method

After the main has been cleaned, potable water with a chlorine residual of at least 50 mg/L is fed into the main until it is full. This is achieved by having a constant flow rate and injecting a hypochlorite solution into the main with a hypochlorinator or using liquid chlorine through a solution-feed chlorinator and booster pump. The chlorinated water should remain in the pipe for a minimum of 24 hours, during which time all valves and hydrants are operated to ensure their disinfection. At the end of the 24 hour period, the chlorine residual must be no less than 25 mg/L or the procedure must be repeated.

b) Slug Method

This method is suitable for large, long mains where continuous feed is impractical. Following cleaning, potable water is fed into the main at a constant rate. Chlorine is added to the water at a constant rate so that the resulting residual is no less than 300 mg/L. The chlorine dosage is continuous for a sufficient period to ensure that the minimum contact time is 3 hours. As the chlorinated water flows past, all valves and hydrants etc. must be operated to ensure their disinfection.

c) Tablet Method

This method is best suited to short, small diameter mains (up to 30 cm (12 inches)). Since the preliminary cleaning must

be forgone it is absolutely essential that during construction the pipe interior remains clean and dry. The calcium hypochlorite tablets must be placed at the top of the pipe using an approved adhesive. The main is slowly filled (flow less than 0.3 m/s (1 ft/s)) to prevent washing the tablets to the end of the main. Sufficient tablets must be used to result in a final chlorine residual in excess of 50 mg/L. The contact time is a minimum of 24 hours after which the residual must be about 25 mg/L. If the water temperature is below 5° C the contact time must be increased.

6.3 Disinfecting Repaired Water Mains

When a leak is minor and the water in the main always has a positive pressure, no disinfection is required after the repair is complete. However, with a more serious break the main must be disinfected before being put back into service. AWWA Standard, C601-68 lists two alternatives. If the broken main need not be put back into service immediately the methods outlined for new mains would ensure better disinfection.

a) Swabbing and Flushing

This procedure is the minimum that may be used. The interior of all pipes and fittings must be swabbed with a 5% hypochlorite solution as they are installed. The chlorine solution can be sprayed on with a small pressurized tank. This is followed by flushing, preferably in both directions, until the coloured water is eliminated.

b) Slug Method

Where possible, the following method should be used. The main with the break is isolated and repaired, then flushed and if necessary foam swabbed to remove all debris. Chlorine is then introduced, as in Sec. 6.2 b), except that the residual may be increased to 500 mg/L and the contact time reduced to ½ an hour.

After the contact period the main is well flushed and then put back into service.

6.4 Bacteriological Testing

After the new or repaired main has been well flushed with potable water, to remove the heavily chlorinated water, bacteriological samples must be taken to test the effectiveness of the disinfection. If the main is very long several samples should be collected along its length. In distribution systems that normally carry a free chlorine residual one sample or a set of samples (in a long main) is sufficient. However in all other distribution systems a second sample or set of samples should be collected after 24 hours. A main is considered adequately disinfected if there are no detectable coliforms in any of the samples.

New mains must not be put into service until the coliform tests are acceptable. The disinfection process must be repeated if they are not.

If possible, repaired mains should also be kept out of service until acceptable results are received. This is seldom possible but if fecal contamination of the main is known or suspected it must be done to prevent a public health hazard. If the test sample(s) are positive for coliforms the disinfection should be repeated.

7.0 Disinfection of New or Repaired Reservoirs

7.1 Preparation

As with water mains, the interior of storage facilities must be cleaned and free of debris before attempting the disinfection process. This is accomplished by washing down the walls and floors with high pressure jet cleaning equipment and/or long handled brushes. All the debris must be rinsed from the tank interior before disinfection.

7.2 Disinfection Procedures

Three methods for disinfection are as follows:

a) First Method

This is suitable for tanks where gross contamination has occurred. The tank is filled with potable water to which has been added, early in the process, sufficient chlorine to result in a 50 mg/L residual when the tank is full. The tank is left for at least 6 hours, preferably 24 hours, then drained to waste and refilled from the regular supply.

b) Second Method

This method can be used in a relatively clean reservoir, such as following routine cleaning or repair. The walls, floor and stanchions are sprayed with a 200 mg/L chlorine solution. The tank is well flushed, filled with potable water from the distribution system and put into service.

c) Third Method

Water containing 50 mg/L chlorine is placed in the tank to such a depth that when the tank is filled the resultant chlorine concentration is no less than 2 mg/L. The water containing the 50 mg/L chlorine is held in the tank for 24 hours before the tank is filled. The full tank in turn is allowed to stand for 24 hours after which the tank may be put into service without draining the water used to disinfect it.

7.3 Bacteriological Testing

After the new or repaired reservoir has been filled with potable water, bacteriological samples must be taken to ensure adequate disinfection. If a free chlorine residual is usually carried in the system only one set of samples is required but in all other systems a second set of samples should be collected after 24 hours.

The bacteriological samples must show no detectable coliforms before a reservoir is put into service. If coliform bacteria are detected the disinfection process must be repeated until satisfactory results are obtained.

8.0 Discharge of Chlorinated Water

Chlorinated water, as used in the disinfection of water mains and reservoirs, can be very toxic to aquatic organisms and it should not be disposed of without careful thought to its effect on the receiving water or sewage treatment plant (STP).

Chlorinated water can be discharged to:

1) Sanitary Sewers - This is a safe course to follow especially if the volume is not great and there is a considerable distance from the point of addition to the STP. However if there is a large volume, eg. with a reservoir, it is essential to contact the municipality to ensure that the operation of the STP is not adversely affected by a hydraulic overload or a massive slug of water with a high chlorine residual.

2) Receiving Waters - This can be detrimental to aquatic life and many fish kills have resulted. Water with a free chlorine residual should not be discharged to a stream or lake. If a combined chlorine residual is present, the concentration at the edge of the mixing zone (where allowed) should be below 0.002 mg/L.

3) Storm Sewer - This should be thought of as directly connected with the receiving water and the same restrictions should apply, even though there could be considerable dilution during wet weather.

4) Drainage Ditch - Discharge to an open ditch is a good alternative, especially if the point of addition is a

considerable distance from the receiving water and the ditch is unlined and is full of weeds and other organic material. Sunlight and high temperatures would help to dissipate the chlorine quickly.

If the above conditions cannot be met, a slow discharge of the chlorinated water to a sanitary sewer or ditch can be used. This is easier and cheaper than dechlorination. If dechlorination is necessary (ie. with direct discharge to a small stream), there are several chemicals that can be used effectively. Adequate mixing and dosage of the chemical with the chlorinated water must be ensured. The amount of dechlorination chemical required can easily be determined from the following equation.

Excess chlorine residual x Factor = Dechlorination chemical required

This can be worked out in mg/L, lb's or what ever units are appropriate.

There are five chemicals that can be used to dechlorinate the water:

1) Hydrogen Peroxide - (Factor = 0.479) - This is probably the best chemical when discharging to an environmentally sensitive water course. It is cheap and an overdose will only add more oxygen to the stream.

2) Sulphur Dioxide - (Factor = 0.901) - This chemical is cheap but it will slightly lower the pH in the receiving water.

3) Sodium Thiosulphate - (Factor = 2.225) - This will cause some sulphur turbidity but an excess is harmless.

4) Sodium Sulphite - (Factor - 1.775) - Excess will lower the dissolved oxygen in the stream.

5) Sodium Pyrosulphite - (Sodium Metabisulphite) - (Factor = 1.338) - Excess will lower the dissolved oxygen in the stream.

For example, a total chlorine residual of 21 mg/L measured in a disinfected water main of 11,000 L (2400 gal) for discharge at only 1 mg/L Cl_2 could be neutralized with hydrogen peroxide. The dosage required would be 20 mg/L x 0.479 = 9.6 mg/L and the total amount needed would be 9.6 x 11000 = 105.6 gm of H_2O_2. This would represent, in terms of 35% commercial grade hydrogen peroxide (sp. gr. 1.13 gm/ml),

$$105.6 \times \frac{100}{35} \times \frac{1}{1.13} = 267 \text{ ml of concentrate.}$$

Date Due
